Simultaneous Feasibility Testing and the System Operator's New Market Systems:

Description

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Contents

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Purpose

This paper provides information about an automated means by which the System Operator will develop and deploy constraints in the management of the New Zealand power system. The new, automated process is expected to be introduced into operational service in the second half of 2008.

Contacting the System Operator

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1. Introduction

This paper summarises the Simultaneous Feasibility Test or “SFT” application which is to be used by the System Operator (SO) to calculate security constraints applied to the SPD application. SFT will come into operation shortly after the SO’s new market systems are commissioned in the first half of 2008.

N-1 security constraints are currently applied to the SPD market clearing engine to ensure the power system is dispatched in accordance with the EGRs and the security policy of the SO’s Policy Statement

1.1 What is SFT?

SFT allows the SO to determine and implement thermal security constraints dynamically, with an objective of providing better management of constraints in real time operation and enabling a more secure, efficient and cost effective use of grid capabilities. It is one of the significant improvements delivered by the MSP project and by better managing constraints accuracy will improve overall power system efficiency.

A dispatch solution output from SFT and SPD is regarded as ‘simultaneously feasible’ because the solution has passed both SPD and SFT feasibility testing.

SFT does not increase the number of security constraints in real time or in final pricing because constraints only constrain the solution (that is, they bind) if they are needed to manage a real security issue. The number of constraints applied in final pricing is not a function of the type of tool used to calculate constraints.

2. Overview of the SFT Application

The SFT application is based on an industry standard AC load flow and contingency programme. A description of the power flow equations solved by SFT is provided in Appendix A.

A high level description of how SFT integrates with other components of the market systems is shown in figure 1.

2.1 SFT Conceptual Difference

The main conceptual difference between the current system (non-SFT solution) and the new SFT world is only the addition of the SFT application. Currently all system limits are applied by the SO to the SPD solution via the market database MDB (shown in bold green and blue in figure 1, below). The green limits are operational power system limits, calculated and entered by the SO. The blue limits are network rating (or branch limits) provided by the Grid Owner and entered by the SO.

2.2 SFT Security Limits

SFT will calculate security limits to manage thermal loading on the power system directly; these are currently a subset of the limits shown in green in figure 1. All other limits, (calculated by the SO to manage system stability) and branch limits (provided by the GO) will continue to be entered into the market system by the SO.

With SFT there are two types of limits applied to the SPD solution:

- limits that continue to be applied by the SO manually (e.g. transmission stability limits), and
- automatic SFT limits to manage thermal security limits (applied during the development of the relevant schedules by SFT).

If any of these limits are within 85% of binding or higher, they become and are defined as constraints in SPD. This represents a change from current terminology, where all limits applied to SPD are defined as constraints regardless of whether they do or ever could actually constrain the SPD solution.

2.3 SFT Constraint Threshold

The percentage threshold can be changed. When SFT is introduced the System Operator proposes to initially use an 85% threshold. With experience, it may prove to be desirable to change the threshold to a greater or lesser percentage. Similarly, a component branch limit above 85% binding will also be defined as a constraint; that percentage may also be changed after operational experience with SFT is gained.

2.4 SFT & Thermal Security Limits

Thermal security limits are currently calculated by off-line engineering studies using an Areva EMS power flow tool and making a number of assumptions about the conditions of the power system that the limits will be applied. The SFT application is based around this Areva EMS power flow tool and uses the same power flow and contingency analysis solvers.

The methodology for generating thermal security limits is summarised in section 6. This includes a description of the additional reactive power assumptions required.

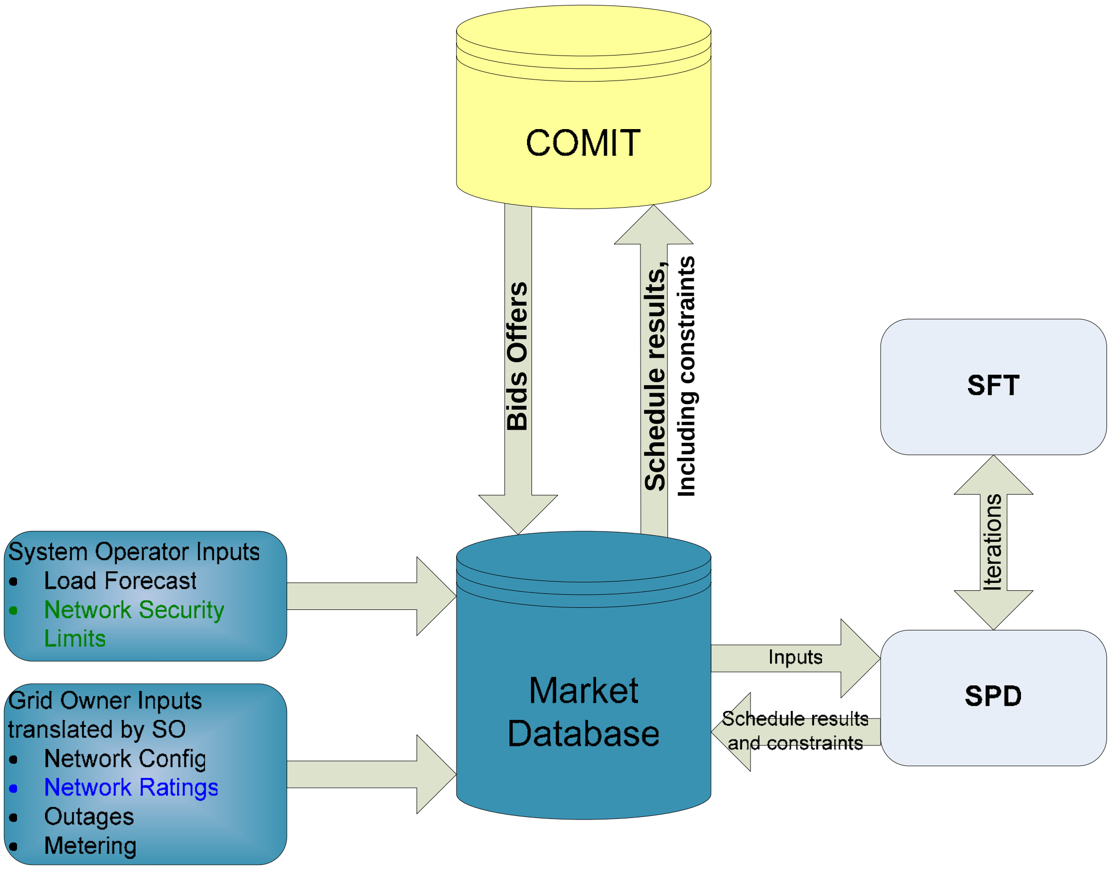

Figure 1 SFT in the Market System

3. Iterations between SPD and SFT

To determine the constraints that will apply to a schedule, SFT and SPD iterate to a solution together. Power system limits and stability limits are incorporated into SPD directly by the SO. The output data from SPD is sent to SFT which then calculates additional thermal limits at the expected operating conditions (effectively, the expected flow on circuits). These limits are then applied back to SPD for a further solution.

In the current environment, the power system limits and stability limits are expressed as permanent constraints and are applied to SPD directly by the SO.

3.1 SFT Schedules

SFT runs on specific schedules (as shown below in figure 2) for a schedule covering a number of trading periods (TP) and with a number of SPD to SFT iterations for each trading period. In figure 2, the number of trading periods considered is “n” and the iteration count between SPD and SFT is “x”. It is likely that the iteration count will be set to 1 for production schedules, due to performance requirements, but this will be confirmed and optimised during testing and ongoing operation.

With reference to figure 2, each trading period of a schedule is solved consecutively with each trading period only being able to commence to be solved when the previous one is complete. The prior trading period solve provides the initial conditions for the subsequent trading period. Trading periods are shown vertically down the figure (a new trading period per row).

The iterations between SPD and SFT for each trading period are shown horizontally across the figure. The first and last solution in the iteration sequence is always an SPD solution.

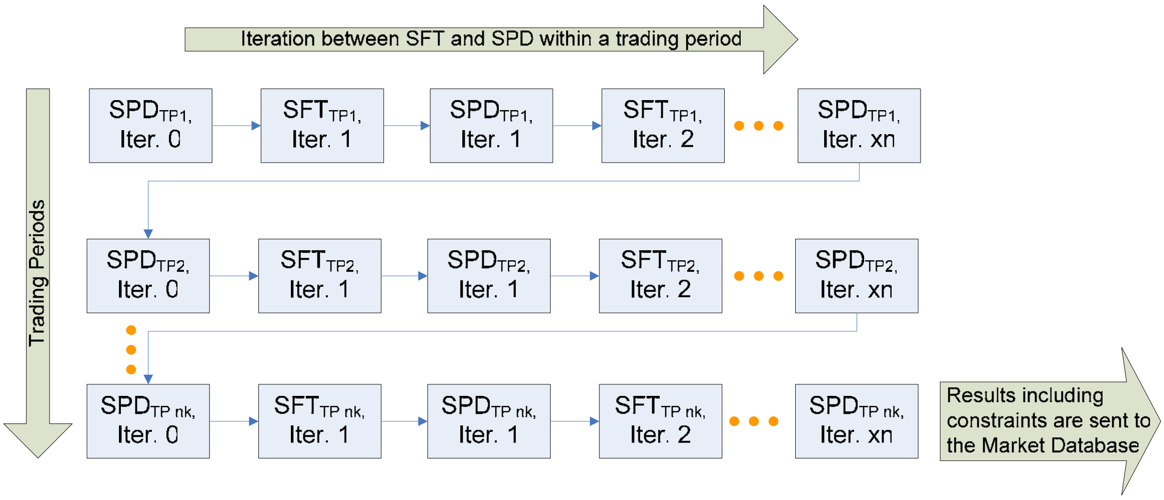

Figure 2 Iteration Diagram

Normally SFT will only run with the WDS, SDS, SDPQ schedules. Constraints from these schedules will be stored in the market database for publication and for application as network limits to other schedules.

In the current market system, each limit is applied to a time period. Any schedule crossing such a time period will have the relevant limit applied. In the SFT environment the limits applied by the SO manually will continue to occur in the current fashion. The limits calculated by SFT will be stored in the market database. When a schedule crossing a time period runs, the schedule will pick up the relevant limits and these will also be applied directly to the first solve of SPD. SFT will only run with specific schedules. The limits are managed differently depending of whether SFT is selected to run or not, as described below. In both cases the limits applied by the SO manually will be applied to all SPD solutions.

3.1.1 SFT not selected to run:

SFT will not normally run with the PDS, RTD, RTP and Final Pricing schedules. For these schedules, the thermal limits calculated from the last schedule with SFT running will be applied directly to SPD as network limits. SPD only runs once (for these schedules) so the limits will become constraints in each schedule if they are above the threshold.

3.1.2 IF SFT is selected to run:

For the schedules running SFT, the thermal limits generated from SFT in previous schedules are only applied to the first SPD solve to help constrain the first SPD solve to a likely operation condition. That is, they operate to give an initial operating condition that helps the iterations of SPD and SFT converge. SFT will then generate limits for subsequent SPD solutions.

4. Publication

Constraints will be published in COMIT with the RTD, PDS, SDS, SDPQ and the new WDS schedules. A diagram showing the timing of various schedules is shown in Figure 3.

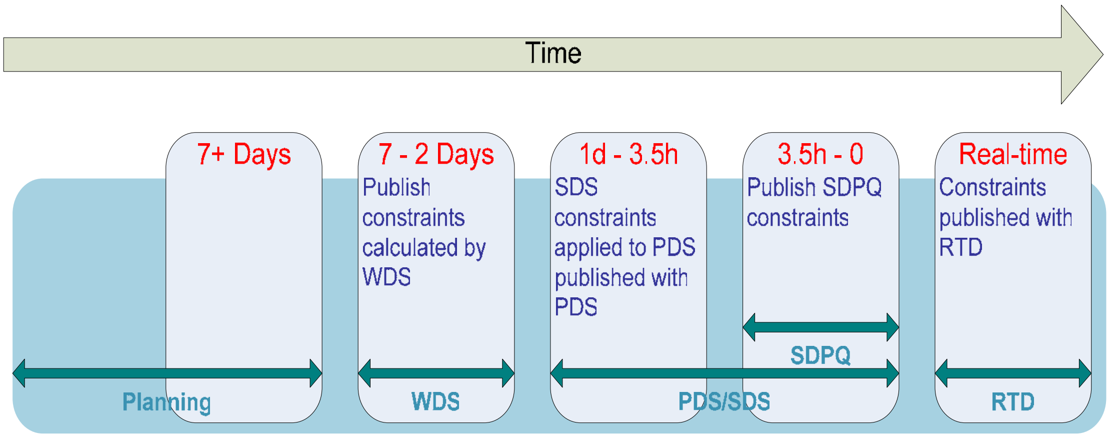

Figure 3 Schedule Timing

4.1 Viewing Constraints in COMIT

COMIT will display the latest constraints calculated for a particular trading period. Users will have the ability to view the history of a particular constraint within a trading period so they can see how the constraint is updated in each subsequent schedule.

The constraint information being created is shown (in tabular form) in figure 4 below.

On each occasion the schedules are run, the constraints are recalculated and updated and automatically account for any changes to offers.

While the new WDS schedule will be used internally by the SO for security analysis in the 2-7 day time horizon, publication of the constraints generated from the WDS is considered the best indication of constraints likely to occur in real time. Publication is consistent with the Policy Statement objective to identify and, by implication, forecast constraints.

Schedule	Description	Timing	Constraint 1	
			Name	%
WDS	The new WDS will be run every day at 1am. The first period is T1 of the next day and it will run for a full 6 days. The WDS will use “rolled over” generation offers from the same day of the previous week, modified by offers received for the relevant period. The offers to be used are at gate closure time for each trading period. For example the Wednesday 17th April T7 forecast offers will be the offers for 10th April T7 at gate closure, 1am on 10th April.	Day 7	1.34*TKU_WKM1.1+ 0.32*TKU_WKM2.1 <120	90
		Day 6…	1.36*TKU_WKM1.1+ 0.31*TKU_WKM2.1 <119	88
		…Day 2	1.34*TKU_WKM1.1+ 0.32*TKU_WKM2.1 <120	85
SDS	Constraints that are within a fixed percentage of binding in the SDS schedules will be published (initially to be 85%). The SDS has the same duration as the PDS but uses the System Operator load forecast. Currently information from the SDS schedule is not published in COMIT.	1pm day before	1.38*TKU_WKM1.1+ 0.29*TKU_WKM2.1 <117	85
		3pm day before…	1.36*TKU_WKM1.1+ 0.31*TKU_WKM2.1 <119	86
		1/2 hour before constraint is required in real time	1.34*TKU_WKM1.1+ 0.32*TKU_WKM2.1 <120	88
PDS	The constraints calculated by the SDS schedule are applied to the PDS schedule. Those constraints that are within a fixed percentage of binding (initially to be 85%) in the PDS schedules will be published.	1pm day before	1.38*TKU_WKM1.1+ 0.29*TKU_WKM2.1 <117	86
		3pm day before…	1.36*TKU_WKM1.1+ 0.31*TKU_WKM2.1 <119	88
		1/2 hour before constraint is required in real time	1.34*TKU_WKM1.1+ 0.32*TKU_WKM2.1 <120	87
SDPQ	The System Operator will publish (in COMIT) a list of security constraints that are within a fixed percentage of binding (initially to be 85%).	3 hours in advance	Will be the same as the SDS results	85
		2 1/2 hours in advance		86
		1/2 hour before constraint is required in real time	RTD and Pricing use these constraints	89
RTD	Uses the constraints calculated from the last applicable SDPQ schedule. If constraints are modified after the last applicable SDPQ schedule then changes will be published with the RTD schedule.		1.34*TKU_WKM1.1+ 0.32*TKU_WKM2.1 <129 RHS Changes normally or Ad hoc updates for major events	94

Figure 4 Constraint Information Overview

4.2 Outage Publication:

Outage information for each schedule will be published in COMIT as a tabular list of scheduled outages. The outage information published will be in the form of real grid component information e.g. BPE_TKU1.1 and BPE CB 62.

4.3 Constraint History Database:

The SFT system will calculate constraints automatically for the given system conditions (the network model, stability limits, outages and offers).

Each constraint is effectively created anew and there can be no generic description of the circumstances when any particular constraint is required.

A historical constraint and outage database will be provided through Comit. Participants will be able to search for either historical instances of outages or constraints; from that data the concurrent constraints or outages that applied at the relevant times can be seen. The database will contain up to 1 year's data.

4.4 List of Manual Security Limits:

The list of non-SFT limits (the transmission capability and system stability limits – formerly permanent constraints), used to manage system stability, will continue to be published on the SO web site. Changes will be notified with the same one-two week notice that is currently given.

5. Real Time and Final Pricing Management

Constraints applied to the RTD schedule are calculated from the last applicable SDPQ schedule. **Note that:**

- The SDPQ schedule runs from the existing period and a further 7 periods (T2 to T8). The constraints calculated for T2 will be locked down and used for the RTD schedules within that trading period.
- If constraints are modified after the last applicable SDPQ schedule then changes will be published with the RTD schedule.
- Under some extreme circumstances the SO may run an additional, "ad hoc" SDPQ schedule. The SO can apply the resulting constraints to the existing trading period for application to RTD immediately.
- The locked down constraints calculated from the SDPQ schedule (trading period T2) are applied to the final pricing solution, to ensure consistency with the EGRs.

6. Constraint process

The process for calculating thermal security limits is shown in the following table. The current and future systems are very similar. The major difference is the high level of automation provided by SFT and the consequent higher levels of accuracy of the limits and constraints produced. Additional details of each of the steps are shown in the table below.

Thermal Security Limit Process		
Step	**Current System**	**With SFT**
1. Forecast likely operating conditions	Medium term outage studies highlight security issue, requiring a limit to be created and applied. Input Assumptions are manually applied to the study	New profiling data is required to estimate operating condition. Generation schedule and grid outages are automatically applied.
2. Identify the need for a limit		SFT CA programme automatically identifies need for limit
3. Calculate Distribution factors	Manually calculated using EMS power flow tool	Automatically calculated using SFT power flow tool
4. Calculate off load time equation and merge with 3 above	Transpower tool manages off load time characteristics	SFT replaces Transpower tool
5. Modify Limit to account for Voltage and Reactive power	Transpower tool allows for manual input of voltage and Q flow at expected operating condition	This data is available from step 2 above and applied
6. Apply to SPD and publish	Current limits are published when applied to time periods in the database	Limits published as described in section 4

Steps 1 and 2: Forecasting the need for a Limit

Because SFT is a full AC load flow programme and SPD based on a DC solution, SFT requires additional information about the real power system.

In the current system, this information is forecast and manually entered by the SO.

With SFT, the information is stored within the SFT application and is maintained by the SO. The information includes the following items:

A. Voltage, power factor and switching profiles.

To account for reactive power components of the power system, the SFT application has profiling functionality which allows the SO to forecast these quantities on a trading period by trading period basis.

The SO will regularly update the profiling data to ensure SFT accurately accounts for reactive power. Accuracy of these profiles is important to the SO because, as well as constraint generation, the SFT application is also used to provide a forward looking security report of the power system. An example of voltage profiling is provided below in figure 5 below. The chart on the left shows the real average voltage profile for 1 month at a substation that is voltage regulated. The chart on the right shows the profile data to be used for the substation for the month.

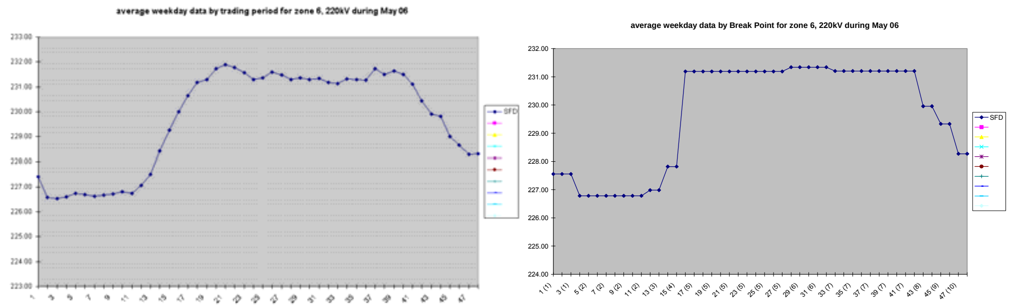

Figure 5 Example of Voltage Profiling

B. Allocation rules for generator units and the HVDC.

SPD provides SFT with a number of station output quantities and total HVDC transfer. SFT works on an individual and detailed component level. For example the SPD solution has a total schedule quantity for a station with 8 units. In SFT the eight units are modelled. This means the SPD output must be distributed across the units using allocation rules (typically based on the relative size of the units at a station).

Step 3: Load Sharing Distribution factors

Consider figure 6 (below) showing the flow on the power system before and after a contingency:

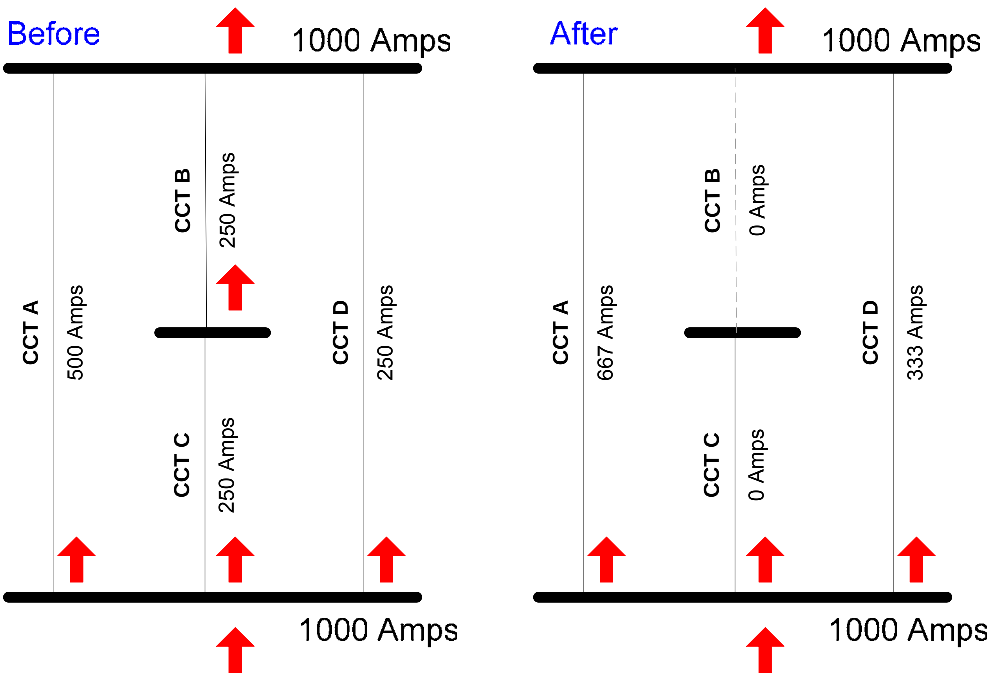

Figure 6 Load Sharing Distribution factors

The Load Sharing Distribution factor is defined as the change in flow on the protected circuit divided by the flow on the contingent circuit.

i.e. Change in circuit A / Initial flow in circuit B

In the figure

- Change in circuit A = 667 – 500 = 167
- Initial flow in circuit B = 250
- Distribution factor = 167 / 250 = 0.667

The distribution factor is largely determined by the impedance of the circuits and where it connects to in the power system. As both are fixed, so is the distribution factor. If the power system configuration changes, typically due to an outage, then the factor can change significantly.

There are also non linear factors; such as, voltage and reactive power flows that mean this is not constant, as discussed in step 5.

The distribution equation can be written

$CCT\ A_{post} = CCT\ A_{pre} + 0.66 \times CCT\ B_{pre}$

Currently these are calculated manually using the Areva EMS application. In SFT, the distribution factor is directly available as an output of the contingency analysis solver in SFT.

Step 4: Off load times / Conductor Thermal Characteristics

The conductor information is supplied by the Grid Owner.

To allow for conductor off load times, thermal inertia needs to be considered.

If a conductor is operated continuously at its thermal rating, which can be translated to its maximum sag limit, any additional loading will cause the conductor to sag below this limit.

When a circuit is initially loaded at 60% it can then be operated for a certain time above its 100% rating, due to thermal inertia. A typical example is shown in Figure 7 and the relationship is not linear. It is essential to estimate the operating condition and linearise the relationship at this point (as shown in Figure 7)

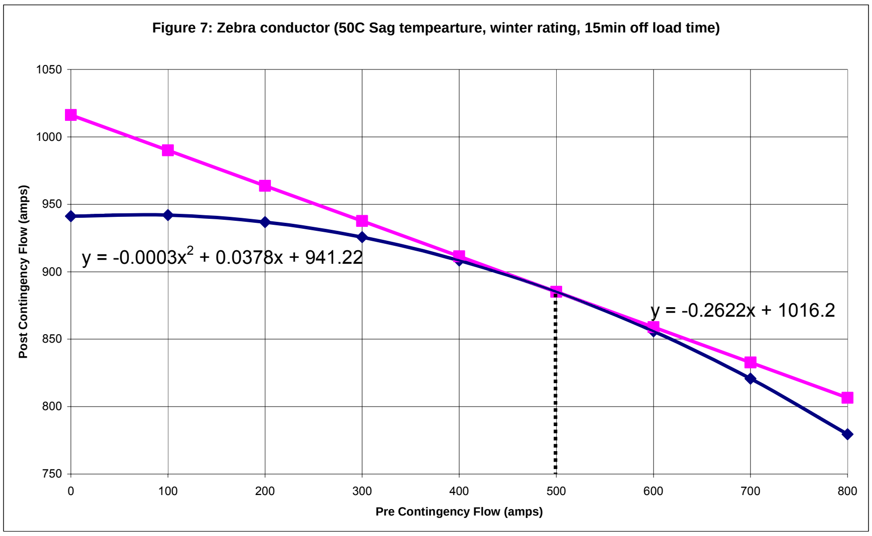

Figure 7 Conductor Thermal Characteristics

The linear equation shown in figure 7 is y = -0.262x + 1016.2

Or $Cct\ A_{post} = -0.26 \times Cct\ A_{pre} + 1016$

Merging this equations with the distribution factor equation from step 5

$CcT\ A_{post} = Cct\ A_{pre} + 0.66 \times Cct\ B_{pre}$

Allows

$CcT\ A_{post} = Cct\ A_{pre} + 0.66 \times Cct\ B_{pre} = -0.26 \times Cct\ A_{pre} + 1016$

This can be rearranged to form an equation with pre contingency flow only: **1.26 x Cct A $_{pre}$ + 0.66 x Cct B $_{pre}$ = 1016**

Currently, Transpower uses a manual tool for calculating the off load time equation and for merging with the distribution factor equations.

In the future, SFT will store line conductor information so that off load times can be fully accounted for within SFT automatically.

Step 5: Modifying the equation to account for Voltage and Reactive power.

The calculated equation assumes the voltages on the power system are all 1pu and that there are no reactive power flows on the network. To compensate, the RHS value of the equation is multiplied by the sending end voltage on the protected circuit, and divided by the reactive power flow injection into the sending end of the protected circuit.

Currently these are entered manually into Transpower's limit calculation tool. In the future, the information is available as an output from the contingency analysis solver in SFT and automatically applied to the limits from SFT.

Step 6: Publication. This is covered in section 4 (above).

Appendix A: Power Flow Equations solved by SFT

The AC SFT uses the “Decoupled Load Flow (DLF)” method which is well established in the industry.

The full power mismatch equations at bus i are written as:

$$\Delta P_i = P_i^{sp} - \sum_{j=1}^{N} |V_i||V_j|\left(G_{ij}\cos\theta_{ij} + B_{ij}\sin\theta_{ij}\right) \quad (1)$$

$$\Delta Q_i = Q_i^{sp} - \sum_{j=1}^{N} |V_i||V_j|\left(G_{ij}\sin\theta_{ij} - B_{ij}\cos\theta_{ij}\right) \quad (2)$$

where,

$\Delta P_i, \Delta Q_i$	Active and reactive power mismatch at bus i
V_i, θ_i	Bus voltage magnitude and angle at bus i
$\Delta V_i, \Delta\theta_i$	Voltage and angle corrections at bus i
$G_{ij} + jB_{ij}$	(i,j) th element of Y bus matrix
P_i^{sp}, Q_i^{sp}	Specified powers at bus i

To solve the full load flow equation we firstly linearise the equations in matrix form as:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = J \begin{bmatrix} \Delta\theta \\ \Delta V \end{bmatrix}; \quad (3)$$

where, J = $\begin{bmatrix} \frac{\partial P}{\partial\theta} & \frac{\partial P}{\partial V} \\ \frac{\partial Q}{\partial\theta} & \frac{\partial Q}{\partial V} \end{bmatrix}$ is called Load flow Jacobian matrix and calculated at the operating point.

In DLF, the sub matrices $\frac{\partial P}{\partial V}$ *and* $\frac{\partial Q}{\partial\theta}$ are not considered as (P-V) and (Q-θ) relationships are weakly coupled, therefore the equation for P and Q are said to be “decoupled”.

$$\Delta P = \left[\frac{\partial P}{\partial\theta}\right].[\Delta\theta] = [H].[\Delta\theta] \quad (4)$$

$$\Delta Q = \left[\frac{\partial Q}{\partial V}\right].[\Delta V] = [L].[\Delta V] \quad (5)$$

where,

H, L Sub matrices of load flow Jacobian matrix

The above set of linear equations can be solved alternately using Newton-Raphson method re-evaluating and re-triangularising matrices H and L at each iteration.

Once the system of linear equations (4) and (5) are solved alternately for $\Delta\theta$ and ΔV, these correction values are applied to update the state vector θ and V. These updated values are used to calculate the bus power mismatches using full system equations (1) and (2). The iteration continues until the maximum bus mismatch is less than, or equal to the pre-defined solution tolerances for both active and reactive powers.

This methodology is used for solving the initial base case solution and also for further contingency analysis where contingencies are applied to the base network one at a time.

Further standard assumptions are made during the contingency analysis to screen the potential harmful contingencies for full solving. These assumptions allow the Jacobian to remain constant during iterations and are almost always valid for practical networks. The mismatch vectors can be further expressed as,

$$\left[\frac{\Delta P}{V}\right] = B^{'}.[\Delta\theta] \qquad (6)$$

$$\left[\frac{\Delta Q}{V}\right] = B^{''}.[\Delta V] \qquad (7)$$

Both B' and B'' are real and sparse and have the structure of H and L sub matrices respectively and contain only network admittances. Therefore they remain constant and only require triangularisation once.